EXPERIMENTAL STUDY OF FRACTURE ENERGY FOR FOAMED CONCRETE

ALSAD BIN NASRULLAH

A project report submitted in partial
Fulfilment of the requirement for the award of the
Master's Degree in Civil Engineering

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I hereby declare that this thesis is my own work except for quotations and summaries which have been duly acknowledged.

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DR. ZAINORIZUAN BIN MOHD JAINI

DEDICATION….

FOR MY DEAREST PEOPLE IN MY LIFE

NASRULLAH ABTAHI

SANDRA HAJI YASSIN

FEWIE NASRULLAH

YASMIN NASRULLAH

ABDUL AZIZ NASRULLAH

MOHAMMAD AIDEE NASRULLAH

SUZIEYANA NASRULLAH

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ABSTRACT

Foamed concrete has recently gained attention as an alternative material to normal concrete in structural engineering. As a structural component, foamed concrete has many advantages given its characteristics such as high strength with low density, good serviceability, and lightweight. Therefore, many studies have been investigated for their strength and mechanical properties. However, literature has shown that there is a lack of research on fracture energy of foamed concrete, which is the main parameter that governs damage and cracks mechanisms of any structural components. Therefore, the present study aims to experimentally investigate the fracture energy of foamed concrete using beam specimens with U-notch and V-notch through a three-point bending test. Fifty-two (52) foamed concrete beam specimens with 100 mm x 100 mm x 800 mm in length with a density of 1600 kg/m³ were cast. The foamed concrete compressive strength of approximately 9 to 10 MPa was achieved at 28 days. Of the fifty-two numbers of beam specimens, two beams were cast as control specimens (with no notches) whilst the forty-eight number of beam specimens was provided with various variables including different notch shapes (U and V-notch), different notch sizes (notch depth to notch opening ratio), and different offset ratios. From the three-point bending test, the peak load, load-displacement profile, and crack patterns for all the beam specimens were highly influenced by the various variables provided. From observation, beams with V-notch with its single corner edge tip and at offset ratio at 0.0 gave higher peak loads and consistent crack patterns compared to beams with U-notch. Increasing the offset ratio reduces the peak load and changes the crack patterns when a combination of shear and bending stress influences the tensile stresses hence the crack direction of the beam. The experimental fracture energy G_F was determined from the classical Hillerborg's model. Three other theoretical models from Bazant, CEB, and JCIS were selected for comparison. For beams with U-notch, Bazant and CEB overestimated its fracture energy by +11.58% and +24.18% whilst JCIS underestimated its result by -30.18%. Similar trends was observed for beams with V-notches when Bazant and CEB both overestimated by +13.33% and 24.48% but was again underestimated by JCIS at -29.16%. However, by modifying the factors from Bazant, CEB, and JCIS equations, a modified theoretical model to measure fracture energy for foamed concrete was successfully developed. This was validated when the modified Bazant, CEB, and JCIS model achieved high accuracy levels at +0.64%, +0.63%, and +1.24%.

ABSTRAK

Konkrit berbuih baru-baru ini mendapat perhatian sebagai bahan alternatif daripada konkrit biasa dalam kejuruteraan struktur. Sebagai komponen struktur, konkrit berbusa mempunyai banyak kelebihan memandangkan ciri-cirinya seperti kekuatan tinggi dengan ketumpatan rendah, kemudahan servis yang baik, dan ringan. Oleh itu, banyak kajian telah dikaji untuk kekuatan dan sifat mekaniknya. Namun, literatur telah menunjukkan bahawa terdapat kekurangan penelitian mengenai energi patah dari konkrit berbuih, yang merupakan parameter utama yang mengatur mekanisme kerosakan dan keretakan pada setiap komponen struktur. Oleh itu, kajian ini bertujuan untuk mengkaji secara eksperimen tenaga patah konkrit berbusa menggunakan spesimen balok dengan takuk U dan takik V melalui ujian lenturan tiga titik. Lima puluh dua (52) spesimen balok konkrit berbusa dengan panjang 100 mm x 100 mm x 800 mm dengan ketumpatan 1600 kg / m³ dilemparkan. Kekuatan mampatan konkrit berbuih sekitar 9 hingga 10 MPa dicapai pada 28 hari. Dari lima puluh dua bilangan spesimen balok, dua rasuk dilemparkan sebagai spesimen kawalan (tanpa takuk) sementara empat puluh lapan bilangan spesimen rasuk dibekalkan dengan pelbagai pemboleh ubah termasuk bentuk takik yang berbeza (takuk U dan V), takik yang berbeza saiz (nisbah kedalaman takuk ke bukaan takuk), dan nisbah ofset yang berbeza. Dari ujian lenturan tiga titik, beban puncak, profil perpindahan beban, dan corak retak untuk semua spesimen rasuk sangat dipengaruhi oleh pelbagai pemboleh ubah yang disediakan. Dari pemerhatian, rasuk dengan V-notch dengan hujung tepi sudut tunggal dan nisbah offset pada 0,0 memberikan beban puncak yang lebih tinggi dan corak retak yang konsisten berbanding dengan balok dengan U-notch. Meningkatkan nisbah ofset mengurangkan beban puncak dan mengubah corak retak apabila gabungan tegangan ricih dan lenturan mempengaruhi tegangan tegangan maka arah retak balok. Tenaga fraktur eksperimen GF ditentukan dari model Hillerborg klasik. Tiga model teori lain dari Bazant, CEB, dan JCIS dipilih untuk perbandingan. Untuk rasuk dengan U-notch, Bazant dan CEB melebih-lebihkan tenaga patahnya sebanyak + 11.58% dan + 24.18% sementara JCIS meremehkan hasilnya sebanyak -30.18%. Trend yang sama diperhatikan untuk balok dengan takik V ketika Bazant dan CEB keduanya melebih-lebihkan sebanyak + 13.33% dan 24.48% tetapi sekali lagi dipandang rendah oleh JCIS pada -29.16%. Walau bagaimanapun, dengan mengubah faktor dari persamaan Bazant, CEB, dan JCIS, model teori yang diubahsuai untuk mengukur tenaga patah bagi konkrit berbuih berjaya dikembangkan. Ini disahkan apabila model Bazant, CEB, dan JCIS yang diubahsuai mencapai tahap ketepatan tinggi pada + 0,64%, + 0,63%, dan + 1,24%.

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CHAPTER 1

INTRODUCTION

1.1 General

Foamed Concrete is a slurry that is created by injecting mortar or cement paste with synthetic aerated foam. In common with most modern implementations of autoclaved aerated concrete, foam concrete contains almost no coarse aggregate, so the term concrete is somewhat erroneous, though both are in the cementitious composites family. Foamed concrete differs from autoclaved aerated concrete primarily by their specific mode of manufacture, as the latter generates its foaming agent/synthetic aerating gas, for foam bubble formation, by employing an in-situ chemical reaction between aluminum powder and lime/calcium hydroxide to generate hydrogen gas. (Concrete Institute, 2013).

The most basic definition of foamed concrete is that it is 'mortar with air bubbles in it.' The air content of foamed concrete may be up to 75% air by volume. In general terms, foamed concrete can be described as a lightweight, free-flowing material which is ideal for a wide range of applications. It can have a range of dry densities, typically from 400 kg/m3 to 1600 kg/m3, and a range of compressive strengths, 1 MPa to 15 MPa (1). Foamed Concrete can be placed easily, by pumping if necessary, and does not require compaction, vibrating, or leveling. It has excellent resistance to water and frost and provides a high level of both sound and thermal insulation. It is very versatile since it can be tailored for optimum performance and minimum cost by choice of a suitable mix design, such examples are pre-cast units. However, foamed concrete is nearly always made on-site and it is made using a mixed design specifically selected for each application or job. Although the material is called foamed concrete, it is not concrete at all. Foamed concrete is a foamed mortar, where the mortar is made from mixing cement, water, and sand with no coarse aggregates. Hence, foamed concrete is not the same as conventional concrete and does not have the same characteristics. It is known that foamed concrete is much lighter and does not have the same strength as conventional concrete. For this reason, foamed concrete and conventional concrete are generally used for different applications, although there are applications where either may be specified. It should also be noted that foamed concrete is not the same as autoclaved aerated concrete, which is a common building material that is frequently confused with foamed concrete. This is because foamed concrete is a much more versatile material than autoclaved aerated concrete.

The application of foamed concrete as a construction material has been studied over the last decade. As foamed concrete has a different mixed proportion of materials than conventional concrete, further studies on its characteristic material behaviour are vitally important. One of the important features that are lacking and needs extensive studies is the fracture mechanics of foamed concrete.

Concrete is the most commonly used material for construction throughout the world. The understanding of its mechanical behaviour, particularly the cracking and fracture behaviour has been developed and matured through the years. Although cracking represents a prominent feature of the behaviour of concrete structures, not only under ultimate loads but also at service states, fracture mechanics particularly on the non-linear strain-softening behavior and its fracture energy (G_F) has generally not been fully utilized in the traditional analysis of structures (see Fig. 1). However, with the introduction and further enhancement of the finite element analysis software, these computational tools have the capacity to include the necessary fracture mechanic

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